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(54) **Three-wire-line vertical interconnect structure for multilevel substrates**

Senkrecht verbindende Anordnung aus einer Leitung mit drei Drähten für Mehrebenensubstrate

Structure d'interconnexion verticale avec conduite à trois fils pour substrats à plusieurs niveaux

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(73) Proprietor: **RAYTHEON COMPANY**
Lexington, Massachusetts 02173 (US)

(72) Inventors:
- **Gulick, Jon J.**
Hawthorne, California 90250 (US)
- **Wooldridge, John J.**
Manhattan Beach, California 90260 (US)

(74) Representative: **Steil, Christian, Dipl.-Ing. et al**
Witte, Weller, Gahlert,
Otten & Steil,
Patentanwälte,
Rotebühlstrasse 121
70178 Stuttgart (DE)

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Description

[0001] The present invention relates generally to vertical interconnect structures, and more particularly, to a three-wire-line vertical interconnect structure for use in interconnecting components disposed on a multilevel RF substrate.

[0002] Design engineers are just now beginning to take full advantage of the flexibility of multilevel substrates for RF circuitry. Good RF performance depends on the ability to transfer power between the various levels of the substrate without introducing excessive additional RF loss. The assignee of the present invention has developed an interconnect structure to provide for this type of interconnectivity that relates to planar radiator and RF interconnects. This is a coaxial feedline approach, but is relatively complicated, and is potentially difficult to fabricate. Furthermore, the coplanar waveguide feedline uses an edge-coupled device which may introduce greater RF loss than the structure of the present invention.

[0003] Active array radars for airborne applications typically require over 2000 transmit/receive modules per installation. Consequently, in order to provide for relatively affordable radars, each transmit/receive module should be made as inexpensively as possible, without sacrificing performance. The use of multilevel substrates provides a means for this goal to be reached, and also reduce the size and weight for airborne and space applications.

[0004] US-A-5,057,798 discloses a space-saving two-sided microwave circuitry for hybrid circuits, wherein a microstrip or coplanar waveguide RF line is formed on the front side and on the back side of a hybrid circuit board containing other components. The connection from the top side and back side RF lines is accomplished by low VSWR plated via holes through the substrate. In one embodiment an inner transition via hole and two outer grounding via holes are aligned for impedance matching.

[0005] From US-A-5,294,897 a surface mountable microwave IC package is known which includes a dielectric substrate. A ground conductor is disposed on a front surface of the dielectric substrate. A microwave IC chip is disposed and grounded on the ground conductor. The ground conductor comprises an upper coplanar line which is disposed on the front surface of the dielectric substrate, and a lower coplanar line which is disposed on the rear surface of the dielectric substrate. An intermediate coplanar line penetrates through the dielectric substrate and connects the upper coplanar line to the lower coplanar line. By this arrangement, a microwave transmission path from the package substrate to the IC chip is provided that maintains a continuous transmission mode.

[0006] It is an object of the present invention to provide an alternative vertical interconnect structure for use in interconnecting components disposed on a multilevel RF substrate that is adapted to transfer power between various levels of the substrate without introducing excessive additional loss.

[0007] This object is achieved by the apparatus mentioned at the outset, wherein the vertical interconnect structure supports transmission of a transverse electromagnetic (TEM) wave.

[0008] In order to meet the above and other objectives, the present invention comprises a three-wire-line transmission structure that is adapted to provide DC and RF electrical continuity between different levels of a multilevel substrate. Prior vertical interconnects have not made use of the particular guiding structure employed in the present invention. The present invention provides a means for transferring power between various levels of the substrate without introducing excessive additional RF losses.

[0009] In a completed electronic circuit employing the present invention, an electronic device is electrically coupled between two coplanar transmission line structures disposed on one surface of the substrate, and the vertical interconnect structure couples power to the electronic circuit by way of the coplanar transmission line structure disposed on another surface of the substrate. Typically, the three conductors of the vertical interconnect structure have a circular cross-section, but are not limited thereto. The conductors are typically comprised of a metal, such as tungsten, or molybdenum, for example. The dielectric material is typically comprised of a ceramic, such as aluminum nitride, for example. The impedance of the vertical interconnect structure is determined by the relative dimensions of the three conductors and their relative separations.

[0010] There are three primary advantages provided by the present invention. It is relatively easy to fabricate, in that vertical wires having a circular geometry are easily accommodated as part of the fabrication process for the substrate. The three-wire-line transmission line structure of the present invention provides for relatively low loss, because of the nature of the currents that flow thereon. Finally, the propagation characteristics of the present structure are well-understood.

[0011] With regard to the active array radars for airborne applications mentioned above, using the multilevel substrates of the present invention provides a means for this goal to be reached. The present invention helps to ensure that those transmit/receive modules that use multilevel substrates satisfy performance specifications. In addition to the cost savings, the depth and weight of the radar are reduced by a factor of about six using the present invention, thus allowing installation of the radar into confined spaces of missiles and spacecraft, and conformal installations on the skins of aircraft.

[0012] The various features and advantages of the present invention may be more readily understood with reference to the following detailed description taken in conjunction with the accompanying drawings, wherein like reference numerals designate like structural ele-

ments, and in which:

Fig. 1a shows a perspective view of an embodiment of a three-wire-line transmission structure in accordance with the principles of the present invention:

Fig. 1b shows a side view of the three-wire-line transmission structure of the present invention;

Fig. 1c shows a top view of the three-wire-line transmission structure of Fig. 1b;

Fig. 2 shows characteristic impedance of the three-wire-line transmission structure of the present invention;

Figs. 3a and 3b illustrate partially cutaway side and top views, respectively, of an exemplary RF structure employing the three-wire-line transmission structure of the present invention;

Fig. 3c shows top and side views, respectively, of the contours of the electric field flux lines for the coplanar waveguide and three-wire-line transmission structure of the exemplary RF structure shown in Figs. 3a and 3b;

Fig. 4a shows another geometrical configuration of the three-wire-line interconnect structure of the present invention; and

Fig. 4b shows the calculated attenuation of a microwave signal as a function of via diameter.

[0013] Referring to the drawing figures, Fig. 1a shows a perspective view of an embodiment of a three-wire-line transmission structure 10 in accordance with the principles of the present invention. The three-wire-line transmission structure 10 is comprised of three conductors 12a, 12b, 12c which are adapted to be embedded in a relatively homogeneous dielectric material 11. The dielectric material may be comprised of aluminum nitride, or alumina, for example. The three conductors 12a,12b,12c are shown having different dimensions, cross-sectional shapes, and relative spacings therebetween indicated as dimensions 2a, 2b, 2c, respectively. The three conductors 12a,12b,12c may be comprised of a metal such as tungsten or molybdenum for example.

[0014] Fig. 1b shows a side view of the three-wire-line transmission structure 10 of Fig. 1a. The illustration of Fig. 1b illustrates how the structure 10 may be used to provide interconnection between two coplanar transmission lines or waveguides 13,14 that are disposed on surfaces of different layers of a multilayer substrate 15. The coplanar transmission lines or waveguides 13,14 are each comprised of respective upper and lower coplanar conductor layers or transmission line layers 16a, 16b having gaps 17 therebetween that transmit RF energy. The use of the present structure 10 works equally well with other types of surface transmissionlines, such as microstrip transmission lines, for example. The three conductors 12a, 12b, 12c are respectively coupled between corresponding coplanar conductor layers of the two coplanar transmission lines 13,14 through each layer (for example conductor layers 15a,15b,15c,15d) of the multilayer substrate 15.

[0015] Fig. 1c shows a top view of the three-wire-line transmission structure 10 of Fig. 1b. The three conductors 12a,12b,12c and the lower coplanar metal layer 16b are shown in phantom, indicating their location below the upper coplanar conductor layer 16a and the multilayer substrate 15.

[0016] The present three-wire-line transmission structure 10 supports transmission of a pure transverse electromagnetic (TEM) wave and consequently the phase velocity in the structure 10 is the speed of light divided by the index of refraction of the dielectric material. The impedance of the three-wire-line transmission line structure 10 is determined by the relative dimensions of the three conductors 12a,12b,12c and their separations, as is indicated in Fig. 2. More specifically, Fig. 2 shows characteristic impedance of the three-wire-line transmission structure of the present invention using air dielectric. This graph applies directly for the case of air used as the dielectric material 11. If the three-wire-line transmission line structure 10 is embedded in another type dielectric material 11, then the impedance values indicated must be divided by the index of refraction of the dielectric material 11 to arrive at the true characteristic impedance for the structure 10. In the general case, all three conductors 12a, 12b, 12c differ in diameter and the spacings are asymmetrical (a,b,c in Fig. 2 correspond to 2a, 2b, 2c in Fig. 1a).

[0017] Figs. 3a and 3b illustrate partially cutaway side and top views, respectively, of an exemplary RF structure 20 employing the three-wire-line transmission structure 10 of the present invention. In the exemplary RF structure 20 the three-wire-line vertical interconnect structure 10 interfaces with a coplanar waveguide 13 on a top surface 17a of an aluminum nitride substrate 15, for example, which in turn terminates at an electronic device, such as a flip chip MMIC device 21, for example. The three conductors 12a,12b,12c are respectively coupled to the individual conductors of the conductor layer 16a.

[0018] A microstrip transmission line 23 is also disposed on the top surface 17 of the aluminum nitride substrate 15 and terminates at the flip chip MMIC device 21. The flip chip MMIC device 21 may be coupled to the coplanar waveguide 13 and microstrip transmission line 23 by means of conventional bonds 24, such as may be made by elastomeric, solder, or z-axis filament bonding techniques, for example. The bottom end of the vertical interconnect structure 10 (not shown) may be connected to a MMIC device on another layer, a silicon VLSI chip, or a radiating element such as a patch antenna, for example in a manner similar to that described for the flip chip MMIC device 21.

[0019] Fig. 3c shows top and side views, respectively, of the contours of electric field flux lines 22 for the coplanar waveguide 13 and three-wire-line transmission

structure 10 of the exemplary RF structure 20 shown in Figs. 3a and 3b. It is apparent that the electric field lines 22 are only slightly perturbed during transition from one structure to the other. This provides for a relatively good, low loss RF transition.

[0020] Fig. 4a shows another geometrical configuration of the three-wire-line interconnect structure 10 of the present invention. Fig. 4 illustrates the spacing of the conductors 12 in a dielectric with a relative dielectric constant of 8.5. With the equal spacing, a 50 ohm transmission line may be created by making the center-to-center spacing S between the conductors 123.2 times the diameter D of the conductors 12. Fig. 4a also shows a keep-clear box 25 at whose edge the electric field is reduced by a factor of 20 compared to the electric field between the conductors 12.

[0021] Fig. 4b shows the calculated attenuation of a microwave signal as a function of diameter of the conductors 12. As the diameter is increased, the conducting surface area of the microwave current within the metal conductors 12 is increased, reducing the resistive loss. As the diameter of the conductors 12 approaches 0,41 mm (16 mils), the resistive loss of the conductors 12 (α_c) becomes equal to the dielectric loss (α_d) of the material 11 (aluminum nitride) and further increase in diameter of the conductors 12 will not reduce the overall loss. The calculation was performed for pure tungsten metal which is used with high temperature cofired aluminum nitride. Typical diameters of the conductors 12 are about 0,254 mm (10 mils), so that the attenuation through atypical 2,54 mm (100 mil) thick substrate 15 is less than 0.02 dB providing excellent transmission of the microwave energy. These calculations have been verified by measurements on aluminum nitrate substrates 15 that are 0,76 mm (30 mils) thick.

[0022] Thus there has been described a new and improved three-wire-line vertical interconnect structure for use in interconnecting components disposed on a multilevel RF substrate. It is to be understood that the above-described embodiment is merely illustrative of some of the many specific embodiments which represent applications of the principles of the present invention. Clearly, numerous and other arrangements can be readily devised by those skilled in the art without departing from the scope of the invention.

Claims

1. Apparatus (10) comprising:

   a multilevel RF substrate (15) comprising a relatively homogeneous dielectric material;
   first and second coplanar transmission line structures (13,14) respectively disposed on first and second surfaces of the multilevel RF substrate (15); and
   a vertical interconnect structure (10) disposed in the multilevel RF substrate (15) that is coupled between the first and second coplanar transmission line structures (13, 14),

   wherein the vertical interconnect structure (10) comprises three conductors (12a,12b,12c) having predetermined cross-sectional dimensions and predetermined separations therebetween that are adapted to transfer RF power between the respective coplanar transmission line structures (13,14) disposed on the multilevel RF substrate (15), **characterized in that** the vertical interconnect structure (10) supports transmission of a transverse electromagnetic (TEM) wave.

2. The apparatus (10) of claim 1, **characterized in that** the conductors (12a,12b,12c) have a circular cross-section.

3. The apparatus (10) of claim 1 or 2, **characterized in that** the conductors (12a,12b,12c) are comprised of tungsten.

4. The apparatus (10) of claim 1 or 2, **characterized in that** the conductors (12a,12b,12c) are comprised of molybdenum.

5. The apparatus (10) of any of claims 1 to 4, **characterized in that** the dielectric material is comprised of aluminum nitride.

6. The apparatus (10) of any of claims 1 to 5, **characterized in that** the impedance of the vertical interconnect structure (10) is determined by the relative dimensions of the three conductors (12a,12b,12c) and their relative separations.

7. The apparatus (10) of any of claims 1 to 6, **characterized in that** the three conductors (12a, 12b, 12c) have different dimensions.

8. The apparatus (10) of claim 7, **characterized in that** the three conductors (12a, 12b, 12c) are aligned, and the inner conductor (12b) having a smaller diameter than the outer conductors (12a, 12c).

9. The apparatus (10) of any of claims 1 to 8, **characterized by**

   a third coplanar transmission line structure (23) disposed on a second surface of the multilevel RF substrate (15); and
   an electronic device (21) electrically coupled to the second and third coplanar transmission line structures (13, 23);
   and wherein the three conductors (12a,12b, 12c) are adapted to transfer RF power between the first and second transmission line structures

(13,14).

Patentansprüche

1. Vorrichtung (10), mit:

   einem aus mehreren Ebenen bestehenden RF-Substrat (15), das ein relativ homogenes dielektrisches Material aufweist;

   einer ersten und einer zweiten koplanaren Übertragungsleitungsstruktur (13, 14), die jeweils auf einer ersten und einer zweiten Oberfläche des aus mehreren Ebenen bestehenden RF-Substrates (15) angeordnet sind; und

   einer vertikalen Verbindungsstruktur (10), die in dem aus mehreren Ebenen bestehenden RF-Substrat (15) angeordnet und zwischen der ersten und der zweiten koplanaren Übertragungsleitungsstruktur (13, 14) angeschlossen ist,

   wobei die vertikale Verbindungsstruktur (10) drei Leiter (12a, 12b, 12c) aufweist, die vorbestimmte Querschnittsabmessungen aufweisen und mit vorbestimmten Abständen dazwischen vorgesehen sind, ausgelegt, um RF-Leistung zwischen den jeweiligen koplanaren Übertragungsleitungsstrukturen (13, 14) zu übertragen, die auf dem aus mehreren Ebenen bestehenden RF-Substrat (15) angeordnet sind,
   dadurch gekennzeichnet, daß die vertikale Verbindungsstruktur (10) die Übertragung einer transversalen elektromagnetischen Welle (TEM) unterstützt.

2. Vorrichtung (10) nach Anspruch 1, **dadurch gekennzeichnet, daß** die Leiter (12a, 12b, 12c) einen kreisförmigen Querschnitt besitzen.

3. Vorrichtung (10) nach Anspruch 1 oder 2, **dadurch gekennzeichnet, daß** die Leiter (12a, 12b, 12c) Wolfram aufweisen.

4. Vorrichtung (10) nach Anspruch 1 oder 2, **dadurch gekennzeichnet, daß** die Leiter (12a, 12b, 12c) Molybdän aufweisen.

5. Vorrichtung nach einem der Ansprüche 1 bis 4, **dadurch gekennzeichnet, daß** das dielektrische Material Aluminiumnitrid aufweist.

6. Vorrichtung (10) nach einem der Ansprüche 1 bis 5, **dadurch gekennzeichnet, daß** die Impedanz der vertikalen Verbindungsstruktur (10) durch die relativen Abmessungen der drei Leiter (12a, 12b, 12c) und ihre relativen Abstände bestimmt ist.

7. Vorrichtung (10) nach einem der Ansprüche 1 bis 6, **dadurch gekennzeichnet, daß** die drei Leiter (12a, 12b, 12c) unterschiedliche Abmessungen besitzen.

8. Vorrichtung (10) nach Anspruch 7, **dadurch gekennzeichnet, daß** die drei Leiter (12a, 12b, 12c) aufgereiht sind und daß der innere Leiter (12b) einen kleineren Durchmesser als die äußeren Leiter (12a, 12c) besitzt.

9. Vorrichtung (10) nach einem der Ansprüche 1 bis 8, **gekennzeichnet durch**
   eine dritte koplanare Übertragungsleitungsstruktur (23), die auf einer zweiten Oberfläche des aus mehreren Ebenen bestehenden RF-Substrates (15) angeordnet ist; und
   ein elektronisches Bauteil (21), das mit der zweiten und der dritten koplanaren Übertragungsleitungsstruktur (13, 23) elektrisch gekoppelt ist;
   und wobei die drei Leiter (12a, 12b, 12c) dazu ausgelegt sind, RF-Leistung zwischen der ersten und der zweiten Übertragungsleitungsstruktur (13, 14) zu übertragen.

Revendications

1. Dispositif (10) comprenant :

   un substrat HF (à haute fréquence) (15) à plusieurs niveaux comprenant une matière diélectrique relativement homogène ;
   des première et seconde structures (13, 14) de lignes de transmission coplanaires disposées respectivement sur des première et seconde surfaces du substrat HF (15) à plusieurs niveaux ; et
   une structure (10) d'interconnexion verticale disposée dans le substrat HF (15) à plusieurs niveaux, qui est raccordée entre les première et seconde structures (13, 14) de lignes de transmission coplanaires ;

   dans lequel la structure (10) d'interconnexion verticale comprend trois conducteurs (12a, 12b, 12c) ayant des dimensions de section transversale prédéterminées et des écartements prédéterminés entre eux, qui sont conçus pour transférer de l'énergie HF entre les structures (13, 14) de lignes de transmission coplanaires respectives disposées sur le substrat HF (15) à plusieurs niveaux, **caractérisé en ce que** la structure (10) d'interconnexion verticale supporte la transmission d'une onde électromagnétique transversale (TEM).

2. Dispositif (10) selon la revendication 1, **caractérisé en ce que** les conducteurs (12a, 12b, 12c) ont une section transversale circulaire.

3. Dispositif (10) selon la revendication 1 ou 2, **caractérisé en ce que** les conducteurs (12a, 12b, 12c) sont composés de tungstène.

4. Dispositif (10) selon la revendication 1 ou 2, **caractérisé en ce que** les conducteurs (12a, 12b, 12c) sont composés de molybdène.

5. Dispositif (10) selon l'une quelconque des revendications 1 à 4, **caractérisé en ce que** la matière diélectrique est constituée de nitrure d'aluminium.

6. Dispositif (10) selon l'une quelconque des revendications 1 à 5, **caractérisé en ce que** l'impédance de la structure (10) d'interconnexion verticale est déterminée par les dimensions relatives des trois conducteurs (12a, 12b, 12c) et par leurs écartements relatifs.

7. Dispositif (10) selon l'une quelconque des revendications 1 à 6, **caractérisé en ce que** les trois conducteurs (12a, 12b, 12c) ont des dimensions différentes.

8. Dispositif (10) selon la revendication 7, **caractérisé en ce que** les trois conducteurs (12a, 12b, 12c) sont alignés, et **en ce que** le conducteur intérieur (12b) a un diamètre plus petit que les conducteurs extérieurs (12a, 12c).

9. Dispositif (10) selon l'une quelconque des revendications 1 à 8, **caractérisé :**

   par une troisième structure (23) de lignes de transmission coplanaires disposée sur une seconde face du substrat HF (15) à plusieurs niveaux ; et
   par un dispositif électronique (21) raccordé électriquement aux deuxième et troisième structures (13, 23) de lignes de transmission coplanaires ;
   et en ce que les trois conducteurs (12a, 12b, 12c) sont conçus pour transférer de l'énergie HF entre les première et deuxième structures (13, 14) de lignes de transmission.

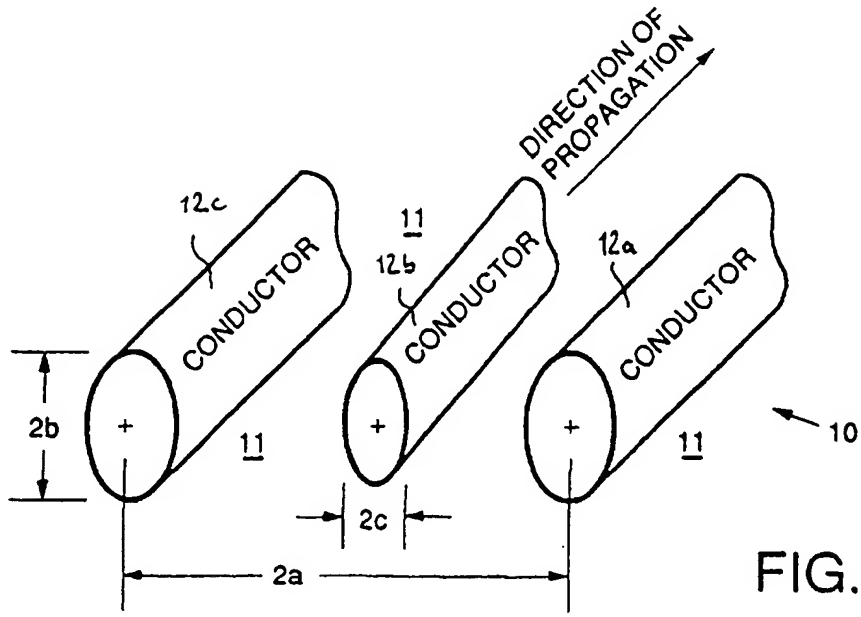

FIG. 1a.

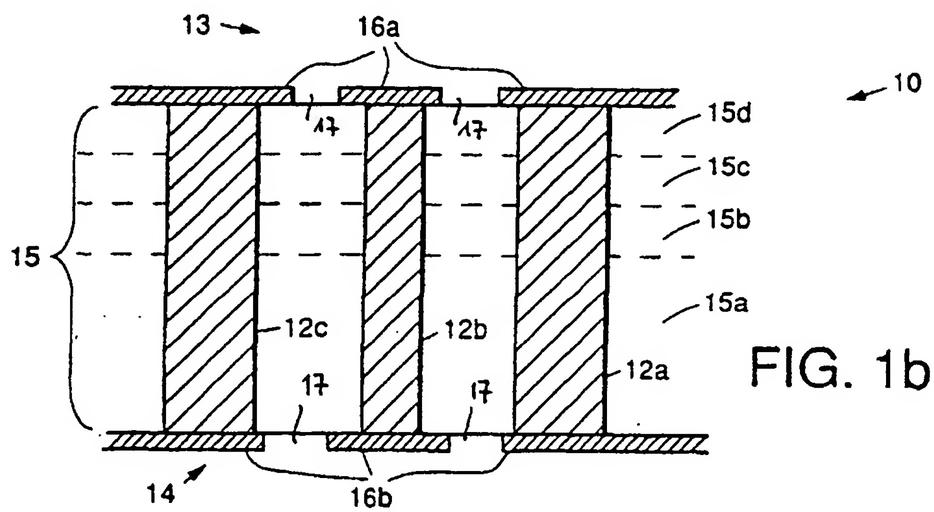

FIG. 1b.

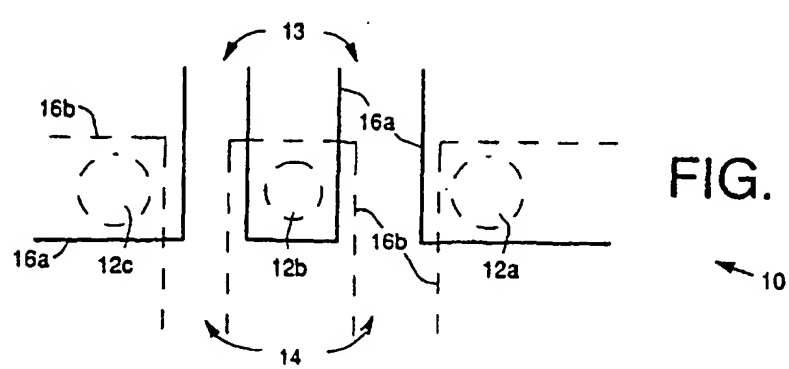

FIG. 1c.

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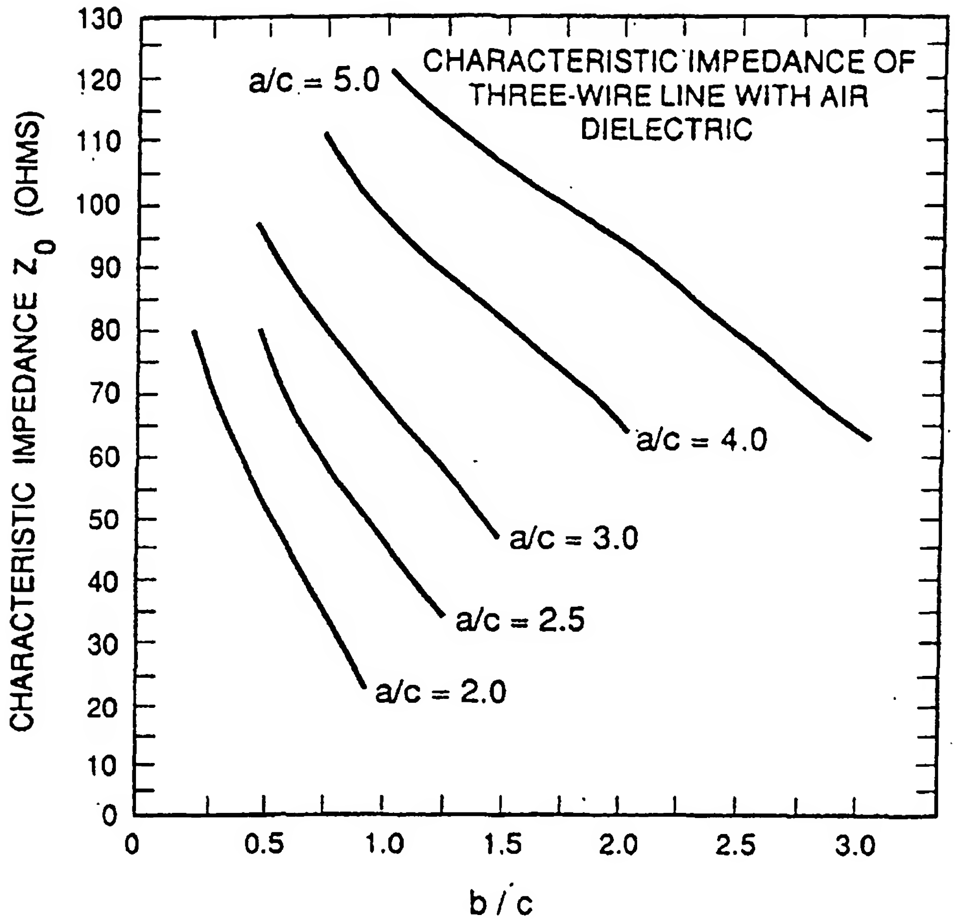

FIG. 2.

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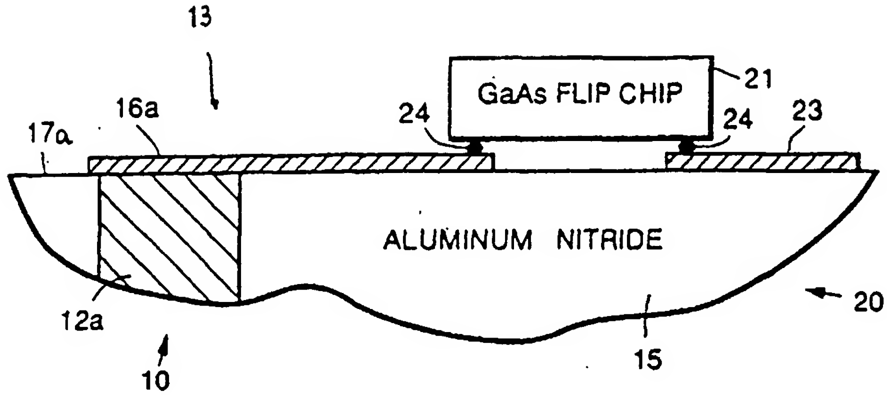


FIG. 3a.

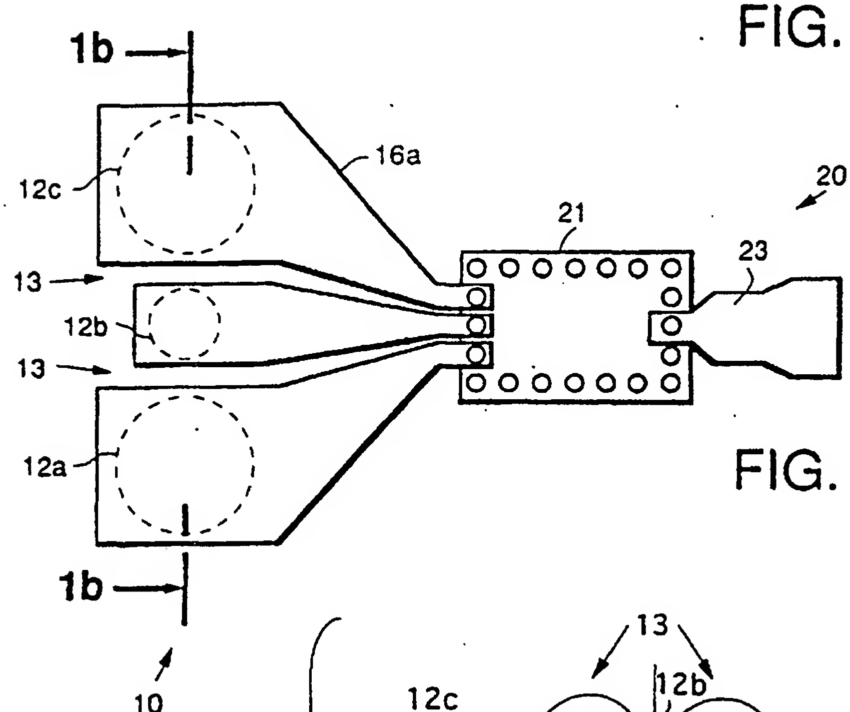


FIG. 3b.

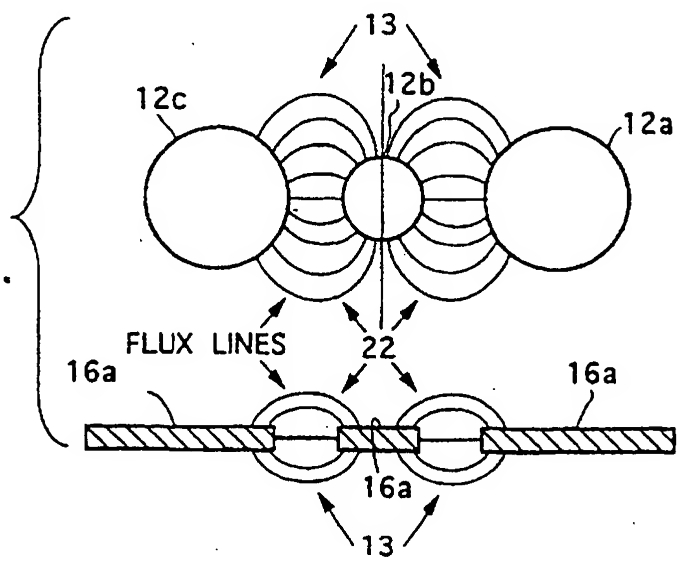


FIG. 3c.

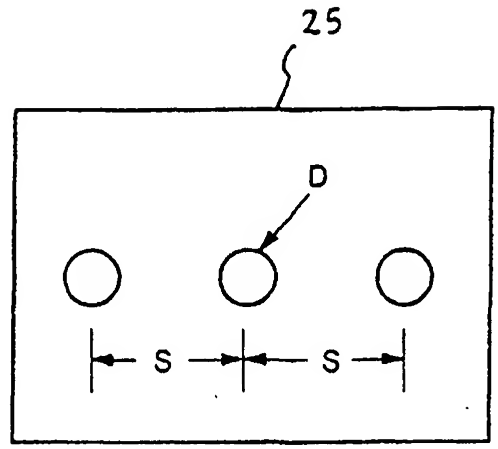
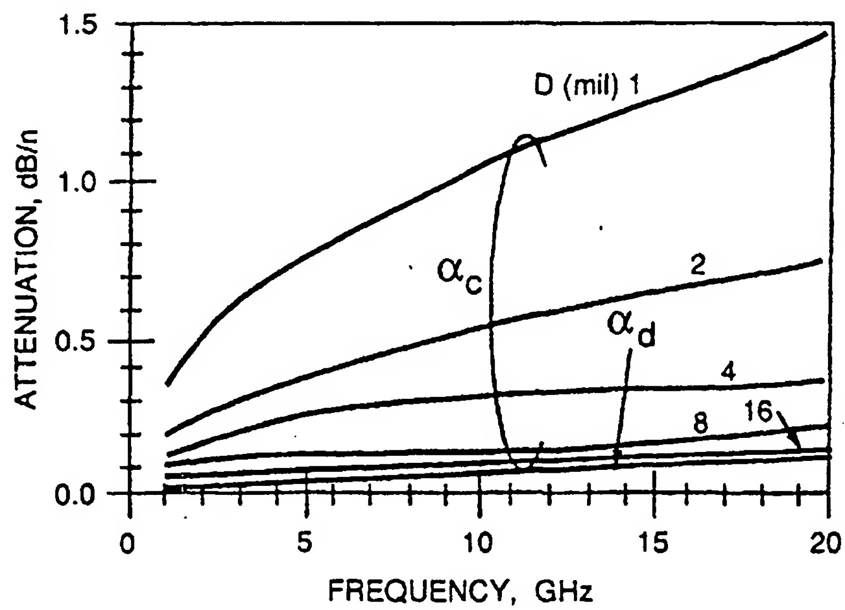


FIG. 4a.

FIG. 4b.



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